

AD-A278 620

Form Approved  
GSA No. 0704-0168

REPORT



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1a. REPORT SECURITY CLASSIFICATION Unclassified			3. DISTRIBUTION/AVAILABILITY OF REPORT See Title Page document has been approved for public release and sale; its distribution is unlimited.		
2a. SECURITY CLASSIFICATION AUTHORITY			5. MONITORING ORGANIZATION REPORT NUMBER(S)		
2b. DECLASSIFICATION/DOWNGRADING SCHEDULE			7a. NAME OF MONITORING ORGANIZATION DCMAO, San Antonio		
4. PERFORMING ORGANIZATION REPORT NUMBER(S)			7b. ADDRESS (City, State, and ZIP Code) 615 East Houston St., P.O. Box 1040 San Antonio, TX 78294-1040		
6a. NAME OF PERFORMING ORGANIZATION SI Diamond Technology Inc.		6b. OFFICE SYMBOL (If applicable) 0HVJ8	9. PROCUREMENT INSTRUMENT IDENTIFICATION NUMBER N0014-93-C-0095		
6c. ADDRESS (City, State, and ZIP Code) 2435 North Blvd. Houston, TX 77098		8b. OFFICE SYMBOL (If applicable) N00014	10. SOURCE OF FUNDING NUMBERS		
8a. NAME OF FUNDING/SPONSORING ORGANIZATION ONR / SDIO		11. TITLE (Include Security Classification) A High Performance Diamond Thin Film Cold Cathode			
8c. ADDRESS (City, State, and ZIP Code) ONR 251B KIJ / Balliston Tower One 800 North Quincy St. Arlington, VA 22217-5660		12. PERSONAL AUTHOR(S) Nalin Kumar and Howard Schmidt			
13a. TYPE OF REPORT Progress		13b. TIME COVERED FROM 10/1/93 TO 11/30/93		14. DATE OF REPORT (Year, Month, Day) 11/30/93	
15. PAGE COUNT 4		16. SUPPLEMENTARY NOTATION			
17. COSATI CODES		18. SUBJECT TERMS (Continue on reverse if necessary and identify by block number)			
FIELD	GROUP	SUB-GROUP			
19. ABSTRACT (Continue on reverse if necessary and identify by block number) See Page 1 of Report					
20. DISTRIBUTION/AVAILABILITY OF ABSTRACT <input type="checkbox"/> UNCLASSIFIED/UNLIMITED <input checked="" type="checkbox"/> SAME AS RPT. <input type="checkbox"/> DTIC USERS					
21. ABSTRACT SECURITY CLASSIFICATION Unclassified					
22a. NAME OF RESPONSIBLE INDIVIDUAL Max Yoder		22b. TELEPHONE (Include Area Code) 703-696 4218		22c. OFFICE SYMBOL 31488	

94-12657

DTIC  
ELECTE  
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S F D

DTIC QUALITY CONTROLLED

94 4 25 069

SECOND PROGRESS REPORT  
( Item No. 0001AB )

Contract Number: N00014-93-C-0095

SBIR Topic Number: SDIO 93-016

**A High Performance Diamond Thin Film Cold Cathode**

November 30, 1993

Principal Investigator

Dr. Howard K. Schmidt  
Chief Operating Officer

Accession For	
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DTIC TAB	<input type="checkbox"/>
Unannounced	<input type="checkbox"/>
Justification	
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Availability Codes	
Dist	Avail and/or Special
<i>A-1</i>	

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2435 North Blvd.  
Houston, TX 77098

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## Summary of Progress

In this reporting period, we have investigated the low power performance of amorphous diamond thin films deposited under various conditions such as laser power, thickness, gas pressure and background vacuum. We have found that higher power density gives better field emission as shown in Figure 1. This has been correlated to a larger number of particles on the sample which seems to increase with increased power density. In addition, the best films seem to have a bulk resistivity in the few hundred ohm-cm range. The reason for this is not very well understood at this time.

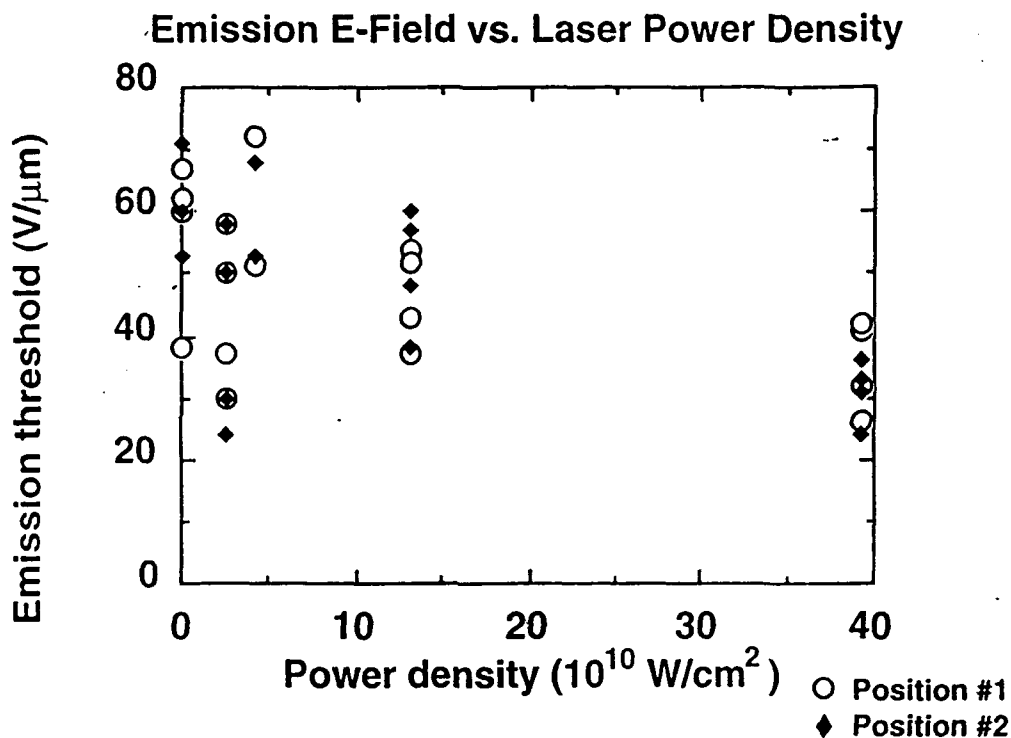


Figure 1: A chart showing the relationship between laser power density and electron extraction field

During these investigations, we have found a phenomenon, which we call 'conditioning'. Conditioning is shown in Figure 2 which shows several successive I-V curves taken on the same point on an amorphous diamond sample. It is seen that a relatively high voltage is required to turn on electron emission when the voltage is applied for the first time. After the first turn-on, the voltage required to emit the same current is decreased. This decrease in voltage is random, but increases with increased maximum current extracted from the sample as shown in Figure 2. This means that a high extraction field sample can be turned into a lower extraction field sample by just

passing a high current through the sample. The exact reason behind this is not known at this time. No damage is observed on the sample surface under the microscope. This phenomenon is of extreme importance to the goals of the project.

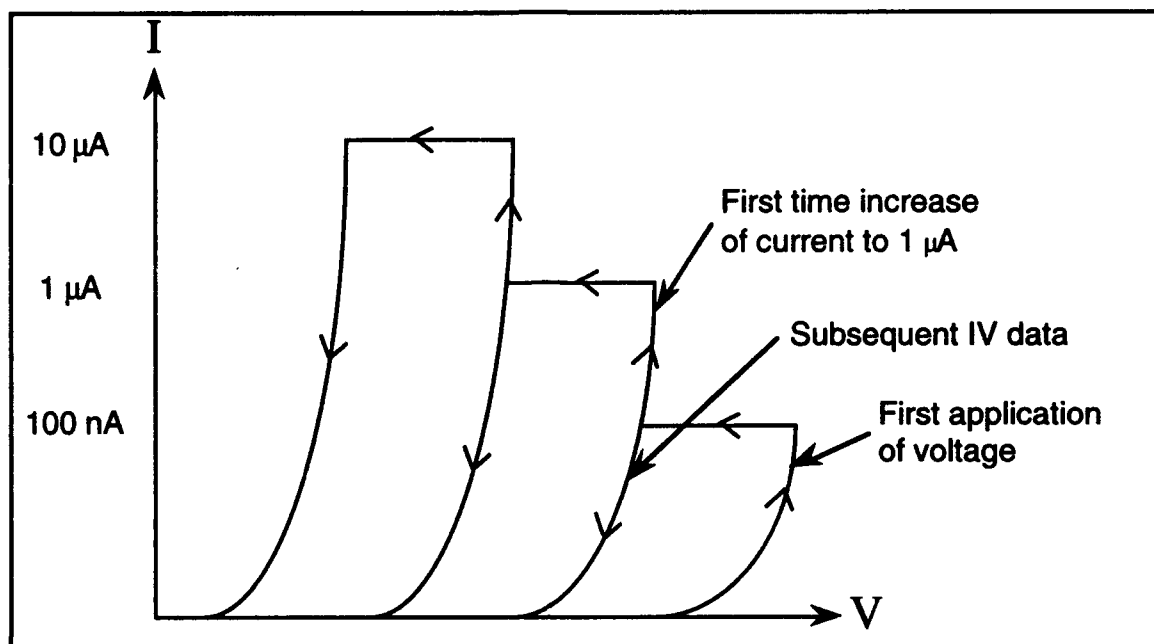


Figure 2. The effect of a cathode conditioning by increase in extracted current.

From the preliminary data taken at low power levels, these cathodes appear to be very rugged. To demonstrate the feasibility of SIDT's amorphous diamond as high current pulse emitter, the relevant DC characteristics of our material have to be determined. We have so far concentrated on completing the set-up and testing of these relevant DC characteristics as well as setting up pulse testing capabilities.

To ensure a material is sufficient for high current pulse applications, one has to make sure that the material survives well at the DC equivalent current density ( $J_{dc}$ ), where  $J_{dc}$  is given by:

$$J_{dc} = Q_{pulse} * \Delta$$

where  $Q_{pulse}$  is the charge per pulse per unit area and  $\Delta$  is the duty cycle..

For the case of a  $1000A/cm^2$  pulse of 1 micro-sec duration,  $Q_{pulse} = 10^{-3} Q/cm^2$ . And  $\Delta = 10^{-4}$  for 100 pulses per second at 1 micro-sec pulses. Therefore

$$J_{dc} = 0.1 \mu A/cm^2.$$

Our testing shows that our material can easily satisfy such requirements and we have extracted currents upwards of  $10 \text{ A/cm}^2$  under dc conditions. We have also done several life-time test runs, one of which is shown in Figure 3. This test was done at  $4 \text{ mA/cm}^2$  which is several orders of magnitude higher than that calculated above. The data shows that there is a lot of noise i.e. the current changes over time but it is random due to the inherent field emission noise. But over all, the cathode does not seem to degenerate even after we have extracted a total charge of more than  $1000 \text{ C/cm}^2$  at  $1000 \text{ V}$  in a vacuum level of  $5 \times 10^{-6} \text{ torr}$ . This compares very favorably with only  $10^{-3} \text{ C/cm}^2$  total charge extracted during a  $1 \mu\text{s}$  pulse of  $1000 \text{ A/cm}^2$ . This means that under pulse conditions, the cathode can survive at least a million pulses of  $1000\text{V}$ .

Though the effect of higher voltage on the ion bombardment energy is significant, it is not expected to be five or six order of magnitude. Hence, we expect the current from these cathodes to be limited by the rate of heat removal from the cathode. Since  $I^2R$  determines the heat generated at the cathode, we strive to obtain as low a resistivity as possible but obtain a broad area emission with larger number of emission sites as well. These are two contradictory requirements and will need to be optimized after careful experimentation. Another approach will be to deposit amorphous diamond on high thermal conductivity CVD diamond to conduct away the heat as quickly as possible.

### EMISSION VOLTAGE vs TIME

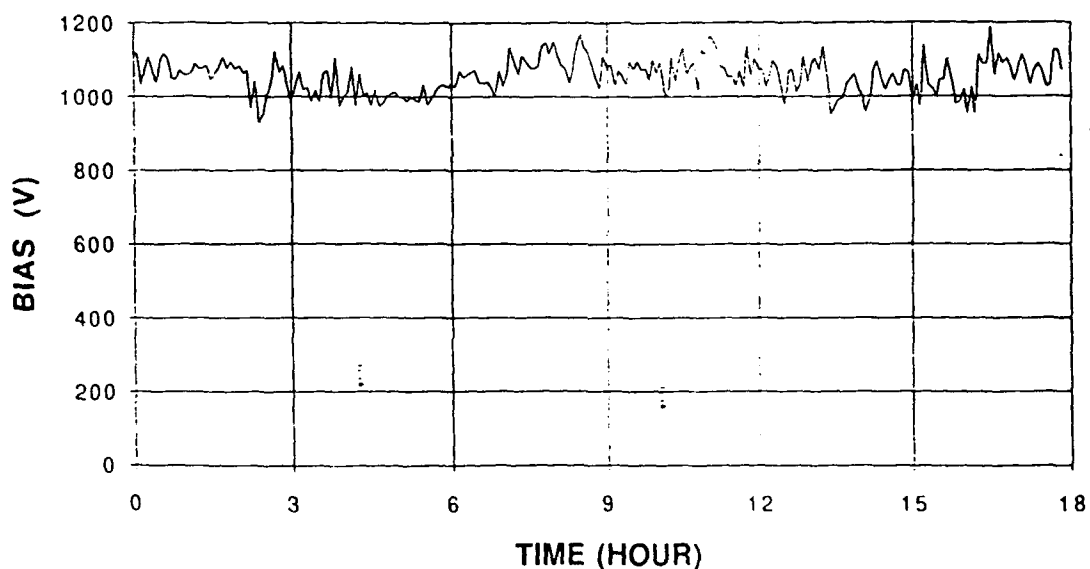


Figure 3. Lifetime data on an amorphous diamond sample at  $4 \text{ mA/cm}^2$  at  $1000 \text{ V}$  and  $5 \times 10^{-6} \text{ T}$  pressure.

In addition to this, we have been designing a new electronic setup which will allow us to do very short pulse measurements. With the new setup, we will be able to go to much higher pulse powers without destroying the test setup. Initial attempts at this failed due to long leads used between the test head and the power supply to the vacuum chamber. This results in a large amount of charge stored in the cable which gives erroneous results due to arcing at the sample. This arcing invariably damages the sample. Figure 4 shows a simple electrical schematic of a new high speed switch which will be mounted directly on the vacuum chamber.

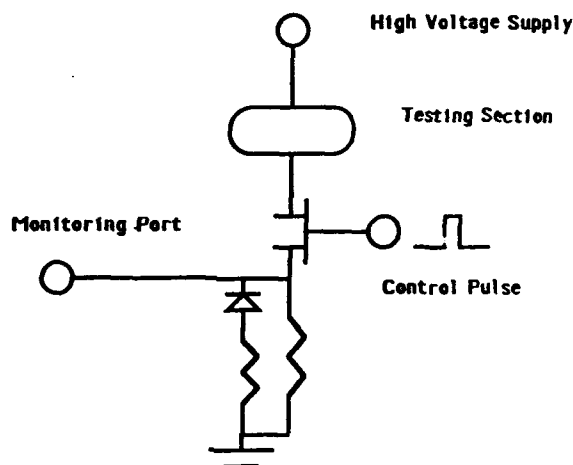


Figure 4. A simple schematic of a circuit designed for pulse testing of amorphous diamond samples at low voltage.

We have found a test facility which will allow us to test on amorphous diamond samples at Phillips Labs in Albuquerque, N.M. We have already received 50 mm diameter beam samples ready to be coated. But we do not expect samples to be tested until April 1994. This will lead to delays in obtaining final results. Hence we are asking for a three month extension of the project.